Culture and low-carbon energy transitions

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Abstract: How does culture positively or negatively influence low-carbon energy transitions? How can insights gained about cultural influences guide local, national and global energy planners and policymakers as they navigate and try to stimulate transitions, particularly during a period of rapid technology change? This Review examines the influence of culture on a selection of low-carbon technologies, behavioral practices, and synergies with different dimensions of sustainability. Based on a typology of low-carbon technology and behavior, we explore the cultural dimensions of four specific case studies: eco-driving, ride-sharing, automated vehicles, and whole house retrofits. While the cases discussed are mainly oriented toward the low-carbon, environmental dimension of sustainability, they also demonstrate the relationship between culture and the equally important social and economic dimensions of sustainability. The Review concludes with policy and research recommendations for those seeking to analyze, understand, develop, demonstrate and deploy low-carbon innovations, practices, and technologies for sustainable energy transitions.

Keywords: energy transitions; energy cultures; sustainability transitions; social acceptance; cultural acceptance; cultural barriers

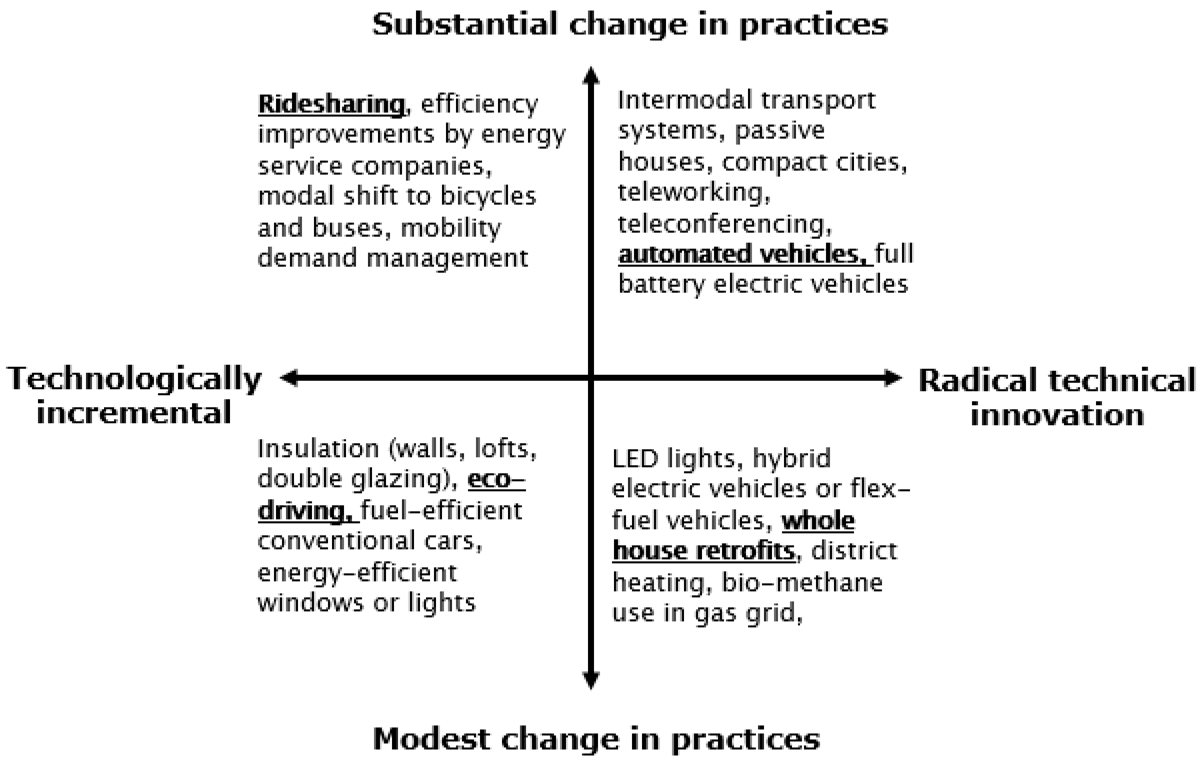
Introduction

In this paper, we review culture and a selection of low-carbon technologies, behavioral practices, and synergies with different dimensions of sustainability. We ask: how does culture influence—positively or negatively—low-carbon energy transitions? How can insights gained about culture guide research agendas, as well as climate and energy planning and policymaking? We take culture as reflection of local societal practices, beliefs and behavioral routines, as well as their socio-material or sociotechnical manifestations. This congeals into a definition of culture as the norms, practices, and material artifacts in a society—at any scale, from individuals and groups to organizations and even nations, a view that is consistent with recent research on energy and culture.[1 2 3] Although various definitions of energy transitions, low-carbon energy transitions, and sustainable energy transitions populate the literature,[4 5 6 7 8 9] we define it concretely as changing the sources or uses of energy technologies or services that ultimately result in lower greenhouse gas (GHG) emissions.

In this Review, we address these global sustainability concerns through a focus on how culture can complicate, or catalyze, attempts at promoting more efficient, more sustainable, and often more affordable forms of mobility as well as energy use in homes and buildings. We offer a qualitative and narrative review of the evidence leveraging data collected across many different disciplines. These include energy and transport studies as well as anthropology, area studies, geography, political science, psychology, and sociology, to name a few. This synthesis of a wide range of studies shows that culture can operate as a salient but often-unacknowledged barrier or enabler to low-carbon transitions as well as sustainability transitions more broadly.

The Review explores culture through the lens of four comparative low-carbon, sustainability transitions summarized in Figure 1. As a guiding theoretical lens, we build on and extend a body of work suggesting that low-carbon transitions and innovations can cut across both incremental and radical technical orientations, and modest versus substantial changes in user behavior modes (or social practices).[10] [11] As Figure 1 indicates, we explore culture and its impacts on the adoption of ridesharing (technologically incremental but radical in terms of practices), automated vehicles (technologically radical and radical in terms of practices), whole house retrofits (technologically radical but modest in terms of changes in practices), and eco-driving (incremental technologically with modest changes in practices).

Figure 1: A technological and behavioral typology of low-carbon transitions



Source: Authors

As Figure 1 reveals, our cultural approach includes social practices as well as particular energy using systems and devices that are the material artifacts of cultural dynamics. It therefore straddles the debate in social science about the role of agency, which sees actors as free-willed subjects, and structure, which sees the external constraints actors or institutions face.[12] Rather than considering culture as the primary result of either agency or structure, we view it as the mechanism that mediates between agency and structure, with the materiality of energy systems or infrastructure shaping this mediation.[13] Moreover, the approach differs from pure practice theory, which takes as the unit of analysis interrelated human, material and discursive elements of practice (e.g. bathing, cleaning, cooking)[14] [15]. We consider how the cultural dynamics of low-carbon transitions are shaped not only by user practices, but also by the technologies and environments that co-exist and co-evolve with practices.[10] This is a particularly relevant framework for our consideration of radical technical innovations, such as autonomous vehicles, where the machine or technology itself takes on culturally determined behaviors.[16]

<u>Eco-driving (technologically incremental and modest change in practices)</u>

Our first example of the interplay between culture and low-carbon transitions centers on the automobile, which has long been identified as a functional technology (for providing mobility) as well as a symbolic and cultural one (for expressing social status and cultural identity). [17] [18] [19] In particular, we examine culture and eco-driving, a term meant to encompass activities that make driving a passenger vehicle more efficient or more environmentally friendly. We classified this as a technologically incremental change (as it still involves cars or simple alternatives such as cycling) that requires just a modest change in practices (such as accelerating or decelerating the vehicle).

Eco-driving is often used interchangeably with “economical driving” or “fuel-efficient” driving.[20] Eco-driving can be categorized into three types: strategic decisions such as vehicle selection and maintenance, tactical decisions such as route planning and weight, and operational decisions such as driving style.[21] Practically, the major factors that enable eco-driving include gentler acceleration and deceleration, smoother driving styles, minimal use of braking, and the avoidance of excessive speed or idling. [22] The social and environmental benefits of eco-driving are diffuse, including maximizing fuel economy, reducing GHGs, and mitigating air pollution. One study noted that 6–18% of eco-drivers reduced their speed and accelerations/decelerations, 9–20% lowered their engine speed, and 5–14% minimize the number of stops.[23]

Culture, expressed in terms of social practices and beliefs grounded in altruism rather than egoism, and environmentalism rather than materialism, has a significant positive relationship with eco-driving. For instance, in terms of strategic eco-driving and vehicle selection, one study of the early adopters of the Toyota Prius found that owners were willing to pay a premium price for a non-luxury vehicle that had a smaller trunk, sluggish engine, and standard cloth seats because it attained excellent fuel economy and symbolized a green identity. [24] Through a series of experiments, the authors found that adopting a Prius signified altruism and a willingness to incur costs for the benefits of others, allowing an owner to brand him or herself as "prosocial individual." [25] Such prosocial behavior was believed to bring significant non-monetary benefits such as being viewed as more environmentally conscious, trustworthy, and even desirable as friend, ally, and/or romantic partner. Such adopters of the Prius especially wanted to be seen out and around the town shopping in their green car. Follow up work has confirmed that "eco cars" have status and symbolic value across diverse contexts, and often marks the adopters as someone who is educated, informed, healthy, and environmentally focused. [26]

Research has emphasized more tactical and operational forms of eco-driving, especially driving style, which can themselves become a way of expressing culture or reflecting cultural practices related to what is known as "driving culture"[27]. In Spain, researchers focused on embedding a culture of eco-driving through a six-hour training course and active monitoring of driving patterns. The Spanish drivers were noted to adopt more eco-driving practices after training and this reduced their fuel consumption by almost 7%. The Spanish driver's vehicles also were observed to have 16% lower revolutions per minute (RPM) on average, 4% lower average speed, 37% lower acceleration and 46% less deceleration.[28]

In certain situations, eco-driving culture can even spillover into the abandonment of the car itself in preference for more sustainable forms of mobility. There is evidence that those belonging to Generation Y (those who were born between 1980 and the early 2000s) are more environmentally aware of their transport choices, less interested in driving or owning cars, and more willing to consider alternative forms of mobility.[29] Particularly in New Zealand, environmental consciousness and concern associate with people preferring lower-carbon transport modes, and awareness of the environmental impact of transport shapes mobility choices.[30] They are also more conscious of the financial costs of driving, and thus, we would argue, to some of the economic costs to driving inefficiently. In the Netherlands, an environmental culture connected to egalitarianism but also active transport has resulted in a strong convention in favor of cycling rather than driving automobiles.[31] [32] Other research has shown how different national cultures spillover into differing cultures of road safety, with Japanese drivers more strongly emphasizing risk reduction and safe driving, whereas drivers in the United States prioritize individual freedom which leads to greater risks and more frequent crashes.[33]

By contrast, behaviors such as tailgating, speeding, traffic weaving, red-light running, and blocking the passing lane are known as "aggressive driving."[34] These behaviors have significant and negative implications on energy use and therefore climate change. In Germany, people's driving styles and route choices have a major impact on exhaust emissions from vehicles. Portable Emissions Measurement Systems have shown that aggressive driving can culminate in much higher emissions than those from normal driving: 20–40% higher for carbon dioxide and 50–255% higher or nitrogen oxide.[35] In Portugal, we see similar results, with aggressive driving leading to increased energy consumption (compared to non-aggressive driving) of more than 200% and emissions about 330% higher.[36] In the United States, aggressive driving is estimated to lower overall fuel economy by 15 to 30% for highway driving and by 10 to 40% for city or urban driving.[37]

How does culture promote aggressive driving practices and therefore run counter to eco-driving? One cultural norm connects masculinity and macho-ness and aggression with the "need for speed." [38] In the United Sates, perhaps due to such conventions and norms, men are more often impatient and frustrated when driving, more likely to waste energy by needlessly revving engines, more likely to display evidence of road rage at traffic lights, and more frequently involved in traffic accidents.[39] These aggressive elements of driving could be prevalent around the world wherever cultures of masculinity, strength, or aggression are strong. One study even referred to such aggressive drivers as "monsters in metal cocoons."[40] In France, these norms of masculinity and assertiveness spawn cultures of "speed" where more than half (56%) of young drivers, many of them male, report that they speed as a habit.[41] Psychological studies of these young French speeders suggest they habitually speed due to strong social pressure from their peers in addition to enhanced perceptions of being able to control time while they speed. [42] Similarly, another study in Denmark concluded that perceptions of speeding among young drivers were strongly influenced by peers compared to other predictors such as education or history of automobile crashes.[43] In Australia, speeding occurs across both genders, with women reporting that they speed because of familiarity with roads, perhaps for reasons of comfort and habit, but men speed because of peer pressure and a stated need to fit in with friends, for reasons of conformity.[44] One meta-analysis also found that anger affects younger drivers more frequently and more negatively, as people generally have an improved ability to control their anger as they get older.[45] A final meta-analysis correlated “sensation seeking,” or those with cultural orientations towards varied, novel, and intense new experiences and the willingness to take risks, with driving practices.[46] It found strong positive correlations between sensation seeking and impulsiveness, risky driving, driving errors, and aggressive driving.

Conversely, while young drivers may seek risks and aggressive driving styles, many elderly drivers do the opposite, and are risk averse. Elderly drivers, for example, are known to be more cautious when merging into traffic, for being more aware of their limitations as drivers, and for having a style that is more considerate.[47] [48] In the United Kingdom, older drivers were even found to be involved in fewer driving fatalities compared to younger drivers.[49]

Other work has emphasized how being cultural pressures to be “macho”, or perceived as strong, dominant, and in control, leads people to speed. As evidence, in Germany young men are overrepresented by a wide margin in road traffic accidents, accounting for almost a third (30%) of all accidents but representing only 8% of the adult population.[50] Interviews with such drivers suggest that “macho identity” creates inclinations of young men towards risk taking—speeding is fun because it is dangerous.[51] In the United Kingdom, cultural norms of assertiveness or macho-ness can even influence the driving styles of those using hybrid electric vehicles. Specifically, some drivers have reported recharging their vehicles not by plugging in to charge via an electrical socket at home or at work, but by aggressively running the internal combustion engine and then braking hard, which taps into the re-generative braking system to “charge” the vehicle.[52] This wastes energy, increases wear and tear on the vehicle, and can entirely offset any carbon savings.[53]

<u>Ridesharing (technologically incremental and substantial change in practices)</u>

Although enabled by the proliferation of internet-connected mobile devices, ridesharing resides in the technologically incremental category (as they again still involve cars as we know them today) but requires more radical changes in practices (such as traveling by a schedule and sharing a vehicle with others). Shared mobility is defined by the Society of Automotive Engineers as the shared use of a vehicle, motorcycle, scooter, bicycle, or other travel mode that provides users with short-term access on an as-needed basis. [54] It involves the sharing of physical assets (i.e. sequential sharing of an asset as in peer-to-peer [P2P] carsharing or bikesharing), and the sharing of rides (i.e. concurrent sharing of an asset by multiple people as in carpooling and ridesplitting). Shared mobility services follow a number of different services models, including membership-based, non-membership-based, P2P, and for-hire.

Carsharing (or a “car club” in the UK and Europe) involves the user paying an hourly (and/or mileage-based) rate to pick up a vehicle, use it, and return it somewhere. [55] Ridesharing most accurately refers to rides or trips that are shared between different individuals and paid separately. [56] Although ridesharing has become somewhat synonymous with ridehailing (or ridesourcing) in everyday language, the two are distinct. Ridehailing is typically defined as an app-based platform that allows users to request for a ride from a (at least semi-) professional driver working for a transportation network company (TNC) — with Uber and Lyft being the most well-known TNCs and the dominant ones in the United States.[55] Ridehailing services are not truly “ridesharing” services unless they exclusively offer shared rides. Similarly, “pooled” ridehailing is not carpooling since the latter generally refers to ridesharing with a non-professional driver. Nonetheless, ridehailing is depicted as one of the most rapidly growing, disruptive forms of shared mobility[57] and it represents an extremely important opportunity for growth in ridesharing. The underlying technology and infrastructure for dynamic ridesharing is rapidly evolving and ridesharing companies are already providing such services[58].

Ridesharing, in turn, can lead to significant material, energy and emissions reductions by minimizing the ownership of automobiles and maximizing their utilization, particularly when they are used for carpooling or ridesplitting (e.g. UberPOOL and Lyft Line) rather than taxi service replacement. [56, 59, 60]When integrated with active travel and mass transit, ridehailing, and all forms of shared mobility, also support walking and healthier lifestyles.[61]

While ridehailing is rapidly building a global reputation, cultural nuances in personal transportation makes ridehailing a service business that requires tailoring to local context. It is therefore not surprising that local ridehailing companies such as Didi Chung in China, Yandex.Taxi in Russia, Go-Jek in Indonesia, Grab in Singapore and Ola in India have succeeded despite the fact that each was a latecomer to ridehailing relative to Uber, which was founded in 2009 and since has had a strong desire to expand its software platform internationally.[62]

The successes of Careem in the Middle East and both Grab and Go-Jek in Southeast Asia have become case studies of competition through cultural awareness [3,63,64,65,66]. In Saudi Arabia, Careem tailored its approach to the Saudi market by training drivers to follow cultural norms about not conversing with female Saudi passengers and not looking at them in the rear view mirror. This cultural awareness enabled Careem to tap into a large Saudi female population.[64] Furthermore, Careem has sought to change the image and perceptions of drivers for hire across the GCC countries, calling them "Captains" to impart a greater level of respect and prestige for the job—and engaging with the cultural pride of Arabs to encourage to become Careem drivers.[67]

In the Philippines and in Indonesia traffic, Grab and Go-Jek launched successful motorcycle ridehailing services with recognition that sharing a motorbike is widely accepted and transport via motorcycles is a norm due to severe traffic congestion and the relative ease with which motorcycles can navigate the traffic[68]. Although Uber did launch operations in the Middle East and Southeast Asia, including a motorcycle ridehailing service to compete with those of Grab and Go-Jek, the company eventually acquired Careem and sold its Southeast Asia operations to Grab. Uber was simply too late in adjusting to cultural factors to compete head on with the local ridehailing companies.

Despite Careem paving the way for the growth of ridesharing in the Middle East, in the countries of the Gulf Cooperation Council (GCC) the norm is private car ownership with 97% of residents traveling predominantly by private car. Further, 32% of GCC residents are unwilling to share a car with others to go to work, which is exactly twice the average percentage of countries across the Middle East and North Africa region. [69] This aversion to ridesharing limits the potential for pooled ridesharing in the GCC and hence limits the potential regional environmental benefits from ridehailing. A key aspect of the individualistic car ownership culture in the UAE and across the GCC is the expression of class and wealth, which is a known automobility frame that is counter to ride sharing.[70] Such views on sharing rides are not limited to the GCC, however. In Demark ride-sharing in the form of car-pooling faces cultural barriers that revolve around notions of safety, social awkwardness, and social exclusion.[71] Riding with strangers is seen as unsafe, the car is viewed as a private and personal thing that strangers are not invited into, and private cars are still associated with strong cultural notions of freedom and emotional satisfaction.[72]

Automated vehicles (technologically radical and substantial change in practices)

Automated vehicles (AVs) serve as our final automobility case and fall at the opposite end of the technology/practice spectrum relative to eco-driving, as they require a radical change in practices (cars no longer even have drivers for full automation) and very advanced technology (further enhancements in automation, artificial intelligence, robotics and manufacturing). In this paper, we follow the SAE International classification system for automated vehicles[73], which is based on six increasing levels of autonomy ranging from

Level 0 with no autonomous driving function to Level 5 with no human intervention required (see Figure 2). The radical AV technology to which we refer is Levels 4 and 5 ("fully automated").

Figure 2: Levels of Partial and Full Automation in Vehicular Mobility

Level 0: **No Automation**	All aspects of driving controlled by human driver. Any automated systems may help with warning but has no vehicle control. For example, cruise control.
Level 1: **Driver Assistance**	Driving assistance system assists human driver with either steering or speed acceleration/deceleration. The driver must be ready to take control at any time. For example, Adaptive Cruise Control and automated steering parking assistance.
Level 2: **Partial Automation**	Driving assistance system assumes steering and speed acceleration/deceleration using driving environment information. The driver carries out all other tasks and must be able to respond if the automated system fails. For example, lane keeping cruise control.
Level 3: **Conditional Automation**	Automated driving system carries out all operational tasks such as steering, braking and accelerating and all tactical tasks like determining lane changes and responding to events. However, the driver must be ready to respond to a request to intervene, or in the event of a system failure. In the event of an accident, the driver remains responsible for any liability.
Level 4: **High Automation**	Automated driving system carries out all aspects of tactical and operational driving, even if the driver doesn't respond appropriately to a request to intervene.
Level 5: **Full Automation**	Automated driving system carries out all aspects of tactical and operational driving in all roadway and environmental conditions that can be managed by a driver. No human intervention is required besides starting the system and setting the destination.

Source: SAE 2016.

The AV case is closely related to our eco-driving and shared mobility cases given that the future of personal mobility is often linked with the broad deployment of AVs that are shared and electric (EV).[74] [75] While the sustainability benefits of car sharing and EVs powered by renewable electricity are clear, the implications of vehicle autonomy are less obvious although linked to key dimensions of mobility, including safety, congestion, GHG emissions and energy consumption.[76] Taiebat et al. reviewed 42 studies that assessed the energy, environment and sustainability benefits of AV technology in various combinations of four dimensions - vehicle, transportation system, urban system, and society. They find that AV-supported transformations at all four dimensions can provide significant low-carbon transition benefits. [77] The studies reviewed indicate that at the vehicle dimension, AVs can achieve fuel savings between 2% and 25%, and occasionally as high as 40%, based on designs oriented toward energy efficiency. However, the long run, net effect of AV technology on energy consumption and GHG emissions is highly uncertain and depends significantly on AV interactions with the transportation system, urban system, and society. Marletto reviewed 20 studies concerning the potential future impact of AVs and found that while increased road safety is nearly universally agreed, the magnitude and type of impact (i.e. positive or negative) on congestion, GHG emissions and energy consumption will depend on a broad range of factors[78]. These factors include transport mode (e.g. car, bus, lorry, train), level of automation (1 to 5), vehicle-to-vehicle (V2V) and/or vehicle-to-infrastructure (V2I) connection, propulsion technology (e.g. internal combustion; hybrid electric, full electric), transport business model (e.g. owned, rented/shared or scheduled) and usage (longhaul, suburban, urban, commuting) and regulatory regime (e.g. defined speed limits, restricted areas of use).

Specifically concerning low-carbon transition, automated light-duty and heavy-duty vehicles can either decrease or increase total road transport energy, with the ultimate outcome depending on how autonomy changes demand for travel and driving practices.[79] The conclusion that broad adoption of AVs can either help or hurt a low-carbon transition has been confirmed in many other studies and reviews as well [80,81,82,83]. While the potential benefit of AVs to low-carbon energy transition is somewhat ambiguous, nearly all of the leading global automobile manufacturers are actively pursuing the commercial introduction by 2020 of vehicles that are not just autonomous, but also electric and shared[84]. This is a promising sign for realizing the potential low-carbon benefits of AVs.

In the case of AV adoption, culture is a critical aspect of both technology adoption as well as technology performance. Several authors have considered how cultural factors support or hinder AV adoption.[85,86] The results suggest that enthusiasm for driving and its social dynamics reduce interest in AV adoption while enthusiasm for the adoption of new technologies increases interest in AV adoption. Concerns for safety (i.e. fewer crashes) and the environment (i.e. lower vehicle emissions, better fuel economy) are driving forces for the adoption of AVs. Potential legal and ethical issues in case of collisions, privacy (i.e. the disclosure of trip data to technology companies), cybersecurity, and hacking are barriers for the adoption of AVs. Demographically, men that are young to middle age and with high incomes are likely early adopters and mainstream users of AVs as are disabled people currently unable to drive[55].

For AVs, however, cultural acceptance of the mode of transportation is not the only consideration for successful adoption. Rather, algorithms in the software guiding the automation can be just as important. The vehicle software contains artificial intelligence (AI) machine learning algorithms that enable AVs to make real-time decisions based on the information they receive from sensors that perceive the environment around them. These algorithms are "trained" to recognize and interpret elements of the environment, such as road signs, pedestrians and vehicles, and then take actions that are "appropriate" based on context.

The process of AI training, however, can result in unintended biases[87] that are difficult to remedy and ultimately reflect varying degrees of racial, gender and/or religious discrimination. Research has shown, for example, that AVs trained using machine learning techniques are likely to have biases in detecting pedestrians based on skin tone (better recognition performance for people with lighter skin tones) and patterns of dress (better recognition performance for those dressed in "Western" clothing compared to traditional "Arab" clothing).[3,88] Such machine biases could also result in an AV not recognizing or misinterpreting the cultural nuances of pedestrian body language, resulting in pedestrian injuries and fatalities.[89], [90] In addition to issues with static and active pedestrian recognition, the "appropriate" action for an AV to take in a pedestrian encounter differs across cultures. The "morale machine" experiment, for instance, has shown a pattern of distinct cultural preferences for privileging the lives of some groups or classes of people over others in the case of an unavoidable AV collision with pedestrians.[91]

Because culture is a driving force in both AV adoption and performance of the technology, a paradox arises whereby societies most favorable towards AVs may not be culturally compatible with their use. For instance, the United Arab Emirates (UAE) ranks very high in KPMG's AV Readiness Index[92] and has a favorable view of AV adoption.[93] However, AV biases that are a byproduct of system training could put darker skinned Arab pedestrians in the UAE at greater risk of not being recognized as pedestrians by AVs. This has raised UAE public concerns about driverless cars being "racist" towards Arabs.[94] Further, the AV paradox does not just pertain to the Arab world. KPMG has ranked the Netherlands as one of the most favorable countries for the use of AVs in all of Europe, given the stated positive public perceptions there of AV technology.[95] However, the Netherlands' strong cycling culture and extremely high number of bicycles per capita creates a dilemma for AV deployment since bicycles are one of the most significant detection challenges for AVs.[96]

Whole house retrofits (technologically radical and modest change in practices)

Whole house retrofits are a departure from the mobility theme and serve as our final case. They exist in the radical technology quadrant (for again requiring entirely new configurations of technologies) but reflect modest changes in practice (as many times the functional attributes of the household remain the same). Whole house retrofits focus on redesigning homes, especially space heating (in Northern countries) or cooling (in tropical countries), to reduce their energy demand and to be more energy-efficient. This is often accomplished through the integration of multiple technologies at once, including fabric insulation, heat pumps and mechanical ventilation heat recovery, energy-efficient lighting, energy-efficient appliances, improved windows, and even integration with renewable energy (such as solar panels and energy storage).[97]

The general benefits of retrofits can be diffuse and vast. One review of rationales for retrofits identified environmental benefits such as displaced carbon, medical benefits such as improved occupant health, economic benefits such as revitalized local enterprises, and equity benefits such as reduced fuel poverty.[98] Retrofits can also produce private benefits to households, including improved property values, and result in major savings on energy bills along with enhanced thermal comfort.[99]

Culture, as with the other cases, can be a motivator for undertaking retrofits. One study, for example, compares British and Indian cultural perceptions of energy efficiency and retrofits, seeking to contrast how an individualistic culture (Britain) differed, if at all, from a more collectivist one (India).[100] The study notes how traditional notions of *Vastu*, or beliefs about the science of architecture, speak to members of the Indian diaspora about the proper placement of doors, windows, and walls, all with a goal of seeking to harmonize energy flows. This means for Indians, the orientation and efficiency of a building attains a level of importance above and beyond that of English respondents without any such beliefs.

Australia has been credited for having a national "love affair" with retrofits due to a "renovation culture" that prioritizes style and aesthetics.[101] There, many homes have implemented retrofits aimed at being low carbon or even "net zero energy," defined as a building with zero net energy consumption throughout the year. Australians have often installed small-scale rooftop solar photovoltaic panels because they are seen as more modern, and overall more beautiful. House retrofit activity in Australia has increased by 150% since 2010, with 10% of Australian property owners undertaking major renovations (of more than $10,000) in the period 2012 to 2014, with the average amount spent of $48,000.[102] The stated motivations for these retrofits, in addition to saving money, are increased comfort, increased value for the property, and, critically, having a home that looks more modern and stylish. As the study concluded, "the core goals of occupant-driven renovations appear to be focused on spatial, functional and aesthetic considerations."

The positive cultural dynamics of retrofits contrast with negative dynamics apparent in Ireland, England, and Japan. In Ireland, one evaluation of the Better Energy Homes scheme concluded that "culture also has a large effect" in the uptake of retrofits, but in the other direction, towards the abandonment of applications.[103] The study noted that stress, disruption, and notions of cleanliness and dirt (not wanting a house to be temporarily dirty) all increase the likelihood of a retrofit being abandoned.

In the United Kingdom, notions of aesthetics and cultural heritage stand in the way of retrofits, with many households preferring to preserve old buildings and not upgrade to newer technologies of building facades.[104] Research has shown that British households are reluctant to compromise the aesthetics of their home or building for the sake of energy efficiency. Interviews with homeowners revealed that many households favored the look of traditional brick facades, wanted to preserve bay windows, wanted to keep cornices and architraves, and expressed a preference for traditional slate and lead roofing. As the study concluded: "every interviewee regarded at least one aspect of their home as important to preserve, on aesthetic or heritage grounds," and that "in all cases there was at least one instance where building preservation had been prioritized over energy and cost savings."[105]

In Japan, retrofits are known to prioritize conspicuousness and social status as much as they are energy efficiency. One study discussed a homeowner who had retrofitted his home with solar panels and LED lights but also four inefficient window air conditioners, because it marked "social accomplishment and standing."[106] Wilhite and Luzenhiser call this the "social loading" aspect of Japanese culture, where cultural norms are built into infrastructure. They argue that Japanese buildings, including retrofits, prioritize air conditioning because it has become associated with modernity and conceptions of what it means to be a progressive Japanese family.[107]

Discussion: Implications for Sustainability and Transitions

In Table 1, we summarize the cultural elements that influence the adoption of the technologies and practices described in our cases. Material artifacts associated with the cases are provided as well as norms, values and practices that may help or hinder adoption. The table shows that regardless of incremental or radical change in technology or practice, culture plays a key role in adoption.

Table 1: Culture as material artifacts, norms and values, and practices in low-carbon transitions

Cases	**Eco-driving**	**Ridesharing**	**Automated vehicles**	**Whole house retrofits**
Technological change	Incremental	Incremental	Radical	Radical
Behavioral change	Modest	Substantial	Substantial	Modest
Material artifacts	Electric vehicles, fuel efficient vehicles	Smart phones, ride-hailing apps, electric vehicles	Automated vehicles, electric vehicles, V2V and V2I communication infrastructure	Homes, fabric insulation, heat pumps and mechanical ventilation heat recovery, energy-efficient lighting, energy-efficient appliances, improved windows, and even integration with renewable energy (such as solar panels and energy storage)
Positive norms and values	Safety, sustainability, risk aversion	Extraversion, sustainability and dematerialization, mobility justice, religious restrictions and aversions to driving	Enthusiasm for new technologies, safety, mobility justice, sustainability, risk aversion	Collectivism and communal wellbeing, responsibility
Negative norms and values	Sensation seeking, risk seeking	Introversion, personal safety, negative perception of professional drivers, convenience, independence, social status from car ownership, social awkwardness, social exclusion	Aversion to new technologies, sensation seeking from driving, risk seeking from driving	Individualism and selfishness, convenience, conspicuous consumption, adopting inefficiency as a symbol of social class
Positive practices	Considerate driving styles, gently merging into traffic, slowly accelerating, selecting vehicles based on safety, fuel-economy, or sustainability	Sharing of personal space and belongings, living in an urban environment	Safe and considerate driving styles, operating a car for utility, selecting vehicles based on safety, fuel-economy, or sustainability	Attaching religious or spiritual significance to retrofits, valuing the aesthetics and style of energy efficiency
Negative practices	Aggressive driving styles, speeding, road rage, selecting vehicles based on acceleration or top speed	Driving as the default form of mobility, living in a rural environment, communicating without a smartphone	Aggressive driving styles, operating a car for pleasure, selecting vehicles based on acceleration or top speed, a threat to cycling (given	Seeking to protect the heritage of inefficient buildings, abandoning retrofits because they interfere with household lifestyles

			problems in detection)	

Source: Authors

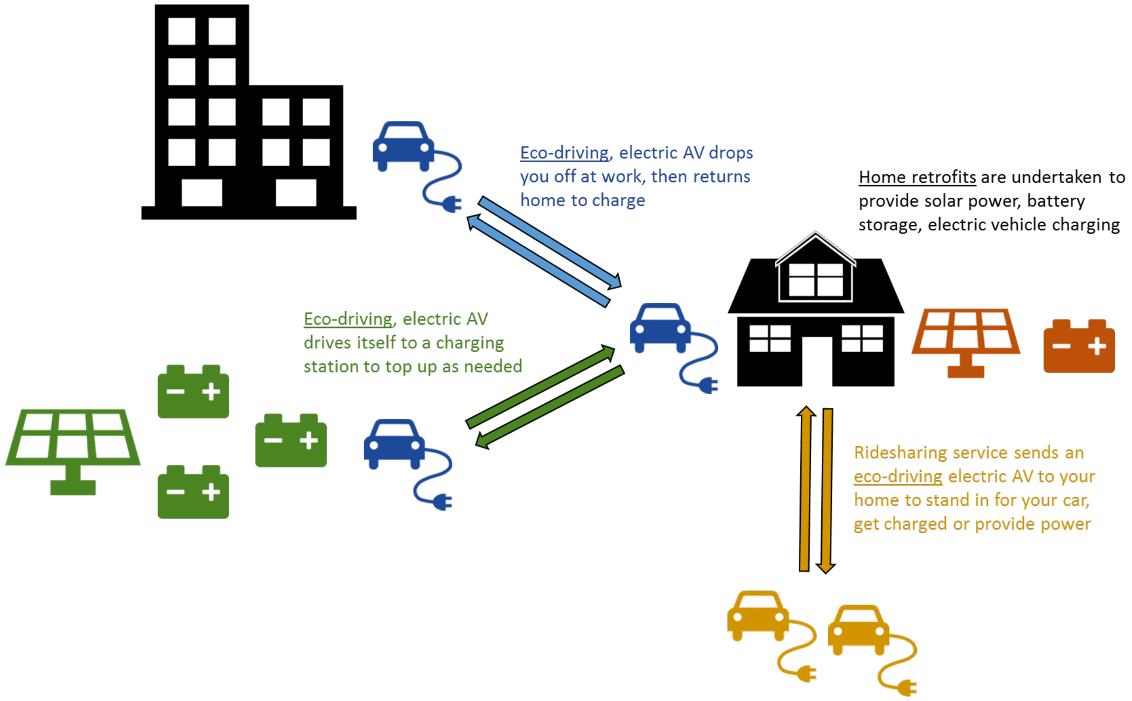
Furthermore, although we treat each of our four innovation and transition cases as distinct, there are factors that can connect them. This includes spillovers and social influence—adopters influencing non-adopters—and households that may adopt multiple innovations. It is already well known within some of the literature of pro-environmental behavior and psychology that one of the strongest indicators of future low-carbon practices is experience or ownership of another existing low-carbon product. That is, for example adopters of electric vehicles (EVs) are more likely to consider adopting other innovations such as solar panels or to eat less meat.[108] Moreover, those who do whole house retrofits could also install EV charging or join a car-sharing group, or vice versa. Finally, consumer research has shown that cultural norms about safety or automotive driving style can be transmitted or shared across different groups, such as families, friends, or organizations.[109]

Therefore, our cases interconnect in compelling dimensions. For example, the trend towards electric, shared and autonomous mobility (i.e. the "three revolutions[75,56]"). From a low-carbon, sociotechnical transition perspective, this combined set of technologies and practices is optimal due to its positive impact on decarbonisation (when EVs are powered by green electricity), dematerialization (from fewer cars and road infrastructure), increased private and public space (from reduced need for parking and possible transformation of private garages to social spaces) and transportation safety. From a purely economic perspective, the continued evolution of ridehailing will pull forward the development AVs through the economic need of TNCs to achieve profitability through the elimination of drivers. By removing the driver from a vehicle, TNCs stand to recover a significant portion of the fare that passengers pay (roughly 80% of every Uber fare currently goes to the driver)[110] while also eliminating the financial incentives they pay to attract and retain drivers[111]. Indeed, "robo-taxis" are expected to be in operation several years before consumer AVs[112] and help spur the sizeable potential energy, environmental and sustainability benefits of AVs.[77] As already noted, however, the proliferation of ridehailing needs to be managed to maximize ridesharing, which is a central element of the noted "three revolutions" in transportation and an opportunity to reduce life cycle GHG emissions per unit distance traveled by as much as 90 % relative to the emissions produced by today's average passenger vehicle.[113]

As also shown in Table 1, AVs (regardless of whether private or shared) and eco-driving culturally intersect via several material artifacts and practices. For instance, both eco-driving and AVs have EVs in common as a material artifact. EVs are a material artifact of AVs because they are the natural platform for AVs in the minds of most consumers[114] and because they have low operation and maintenance costs, which will benefit the high utilization expected for AVs[115]. Furthermore, eco-driving is a natural practice for AVs because it results in improved safety and fuel efficiency, thus lowering insurance and energy costs.

As previously noted, norms and values that relate to environmentalism can spur those who undertake whole house retrofits to also install EV charging or join a car-sharing group. Looking forward and as depicted in Figure 3, the environmentally conscious homeowner may in the future have the opportunity to install EV charging infrastructure that is complimented by distributed solar energy with battery storage that, at least partially, may come from shared electric AVs. Consistent with the spillover of environmentally aligned norms and values, the homeowner that adopts clean energy would potentially see the great benefit of providing a service that would support clean electrification and sharing of AVs, which are the key aspects of making widespread AV adoption environmentally sustainable [56]. Of course, the opportunity for revenue generation from shared EV charging makes this concept economically as well as environmentally sustainable. From this example, it is clear that even cases without an immediately obvious connection can align through shared norms and values as well as related material artifacts.

Figure 3: Interconnections between Electric Vehicle Adoption, Ridesharing, and Automated Vehicles



Source: Authors

From a low-carbon, sociotechnical transition perspective, one may consider a focus on the radical/substantial changes that bring the greatest benefits, encompass other more modest/incremental changes and themselves bring about cultural changes that support transition. As an example of the last point, automakers today provide branding taglines such as "The Ultimate Driving Machine" (BMW) and "Find New Roads" (GM) that reinforce norms and practices that negatively impact the adoption of eco-driving, AVs and vehicle sharing. [116] However, as ridesharing and AVs proliferate, norms, values and practices are apt to shift away from the thrill of driving and freedom of personal car ownership to the efficiency, productivity and peace of mind that being driven safely can provide.

As a final point, our research points the way towards a future research agenda focusing on other elements of culture. For example, our unit of analysis here has been a particular low-carbon innovation or transition, rather than policy, but analysis that identifies successful policy interventions related to cultural awareness about sustainability would be promising to pursue. This said, successful policy cases studies are not available for radical technology innovations, such as AVs, when the innovations are still in the development stage. In the case of AVs, little effort has been dedicated to analyzing how consumer preference for AV technology, vehicle ownership, and ridesharing might evolve. [77] This is very important given that the potential environmental benefits of AVs significantly depend on the extent to which AVs are shared versus privately owned. Research is needed to identify the factors that will affect these choices and overcome cultural norms that may lead people to avoid sharing transportation with strangers, especially if cost differences are insignificant.

Although we show that culture can affect the uptake of technology and that culture can mediate how technologies are designed, technology itself can also alter cultural attributes (e.g. practices, norms), and cultural attributes can affect how technology is used (e.g. as technologies become part of culture).[117] [118] These themes deserve further analysis. Similarly, Norgaard [119] writes not only about cultural barriers or practices, as we have done, but other elements such as cultural toolkits and resources and cultural constructions. Exploring such toolkits and constructions in the context of sustainability transitions would also be fruitful.

Conclusion and Policy Implications

Low-carbon energy transitions are not based only or merely on techno-economic dimensions and considerations. Rather, they are shaped—in positive and negative ways—significantly by culture. The cultural implications of transitions, however, require new forms of research, new data, specialized input of local communities and possible reforms to our energy and climate planning processes. How can planners and policymakers grapple with culture in their interventions to support a low-carbon energy transition, underpinned by a rapidly evolving technology landscape? We briefly consider policy implications and then offer three sets of suggestions for three different stakeholder groups: policymakers and planners, practitioners and researchers of energy development programs.

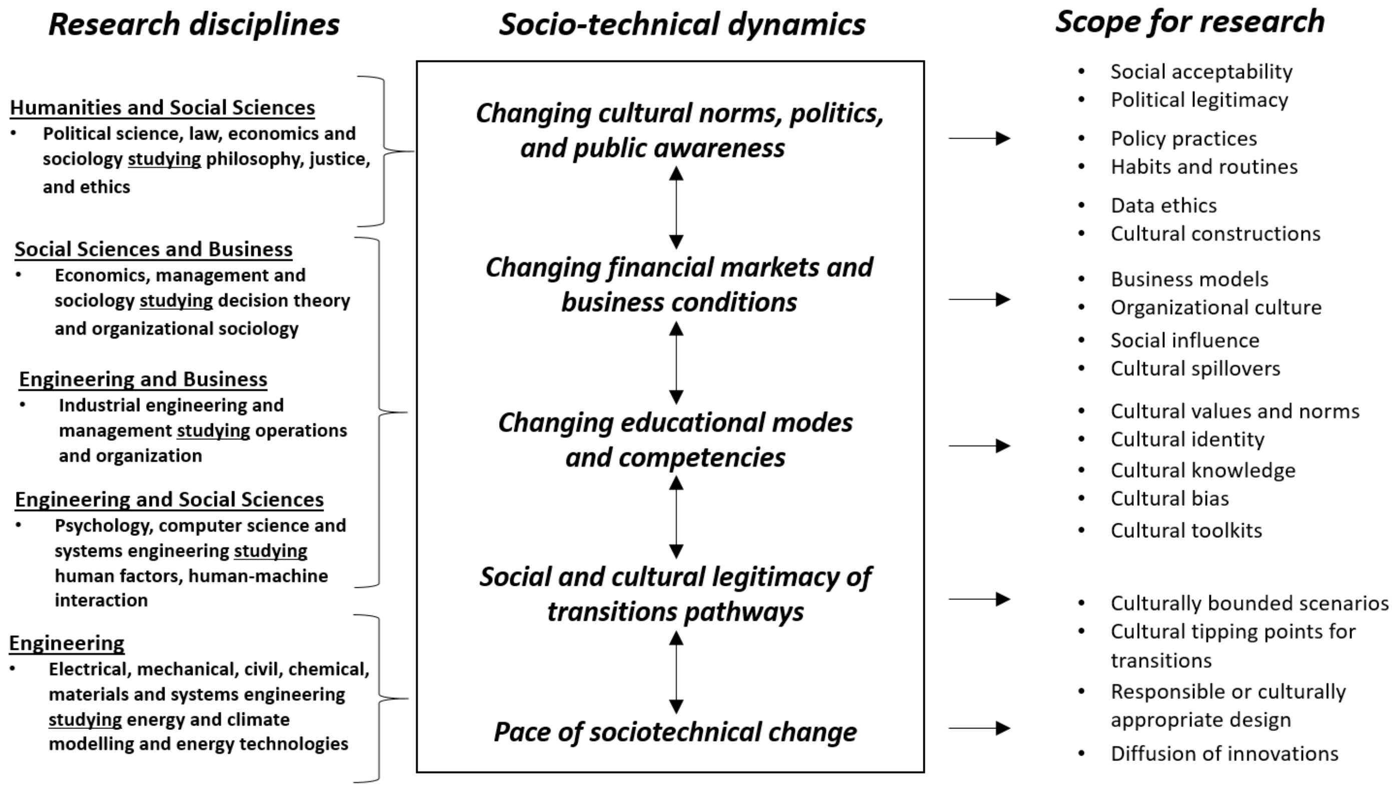
As previously noted, policy interventions related to cultural awareness about sustainability are important. Particularly for radical low-carbon innovations, broad adoption will often require the development of comprehensive and mutually supportive policy packages to increase the likelihood of public and political acceptability and hence the likelihood of effective implementation.[10]. The interconnectivity between our cases demonstrates this need for integrated policy planning as isolated policies for individual low-carbon technologies and practices can influence the adoption of many others (for better or for worse). With regard to the development and structuring of policy packages for sustainability transitions, the literature highlights the need to integrate environmental economics, innovation studies, and policy sciences perspectives[120]. Based on the considerations provided in this paper, we urge a social science/cultural perspective as well. With the case of ridesharing as an example, in contexts such as the GCC cultural barriers make adoption of ridehailing, let alone ridesharing, a challenge and hence the barriers need to be proactively understood and systematically addressed by policymakers. This consideration of policy directly feeds into our suggestions for stakeholder groups.

Governments and intergovernmental organizations at local, subnational, national, and transnational scales—especially those that have ministries, departments, units, or agencies responsible for statistics on energy, climate, transport and buildings—should begin to collect more reliable and comprehensive data on culture and cultural trends. While there is no single format for collecting such data, there are established best practices for collection and subsequent analysis. [121] For instance, an understanding of the potential cultural barriers and enablers to adoption of a particular low-carbon energy technology in a given context might be derived from qualitative interviews, focus groups, observation or even media or content analysis. The latter mode of data collection can further leverage the growth in social media for understanding perceptions of energy. [122] In addition to data collection, governments could stipulate greater community involvement during licensing and permitting discussions so that cultural bias is minimized.

Energy and climate consultants, program managers, and practitioners have a role to play as well. They should offer more meaningful consultations with community members and other stakeholders about their energy services and mobility needs, or their preferences about climate change mitigation. This should occur *before* programs are implemented rather than *after* they are already being implemented. In addition, their efforts should not focus only on the criteria of lowering cost (improving affordability) or improving performance (improving environmental sustainability). Alongside affordability and sustainability, planners should also strengthen the institutional capacity of community-based organizations to shape or manage transitions, and directly seek to educate or inform users about the low-carbon or low-energy technologies they may encounter. Pragmatically, this suggestion entails moving well beyond only "post-hoc monitoring" or "after sales service" to directed hands-on training and maintenance sessions, often on a continual and repetitive basis. Moreover, rather than perhaps promoting Western or imported technologies for a particular region, programs could incentivize more locally designed, culturally acceptable "appropriate technology."[123] This preference for appropriate technology could push for technology that is designed, manufactured, and/or owned by stakeholders who better comprehend the cultural dynamics of the customers they are supposed to serve.

In the research domain, given that culture is a concept that cuts across many academic disciplines (see Figure 4), we have recommendations that span many different segments of academia and the professional community. (Figure 4 also shows how different levels of "culture" can interact with each other). Energy system modelers can be trained in "data literacy"[124] and "algorithmic justice" [16] to become sensitized to cultural diversity and ways to minimize the types of racial, gender, and cultural biases discussed in this paper. These same modelers can be trained to take into consideration expected paces of technical change when bracketed and bounded by cultural factors. Likewise, research and debate can take place among political scientists concerning cultures of energy and climate policymaking; among sociologists concerning the durability of cultural norms and practices related to low-carbon innovations; and among psychologists concerning cultural decision-making criteria and values, to name a few.

Figure 4: A research agenda for culture and low-carbon energy transitions



Source: Authors, inspired by [125] [126]

Furthermore, the funders of research or the principle investigators designing projects could be encouraged to include cultural components and research questions in qualitative projects that collect data via interviews, focus groups, and other public fora, helping to make cultural dynamics visible. Finally, the rapid proliferation of AI across energy and environment sectors[82,127,128] necessitates a broad scientific research agenda to study the embodiment of culture in the machine behavior of energy and environmental technologies. Although we've specifically considered AI as it relates to AVs, in coming years it's capabilities in prediction, optimization and discovery of insights from data could make it central to other low-carbon energy activities, such as ridesharing and smart home energy management. As a positive development, in recent years researchers have come to understand the critical importance of adopting social science perspectives in both energy[120] and AI research[16]. Now is the time to leverage this clarity and bring together interdisciplinary research efforts to ensure that low-carbon transitions are helped, and not hindered, by the embodiment of culture as we seek to decarbonize our future homes, communities, and countries.

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